LOX/Methane
The Future is Green

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The Propellant Choice – a Look into History

- In early days of rocketry, focus on **Gasoline** and **Alcohol**-family
- Developed towards **Kerosene**, later on with **RP-**standards to ensure reproducible quality
- Storable propellant (**Hydrazine** based) driven by space & military application
- High performance focus on **Hydrogen** (first announced by *Ziolkowski* in 1903!)

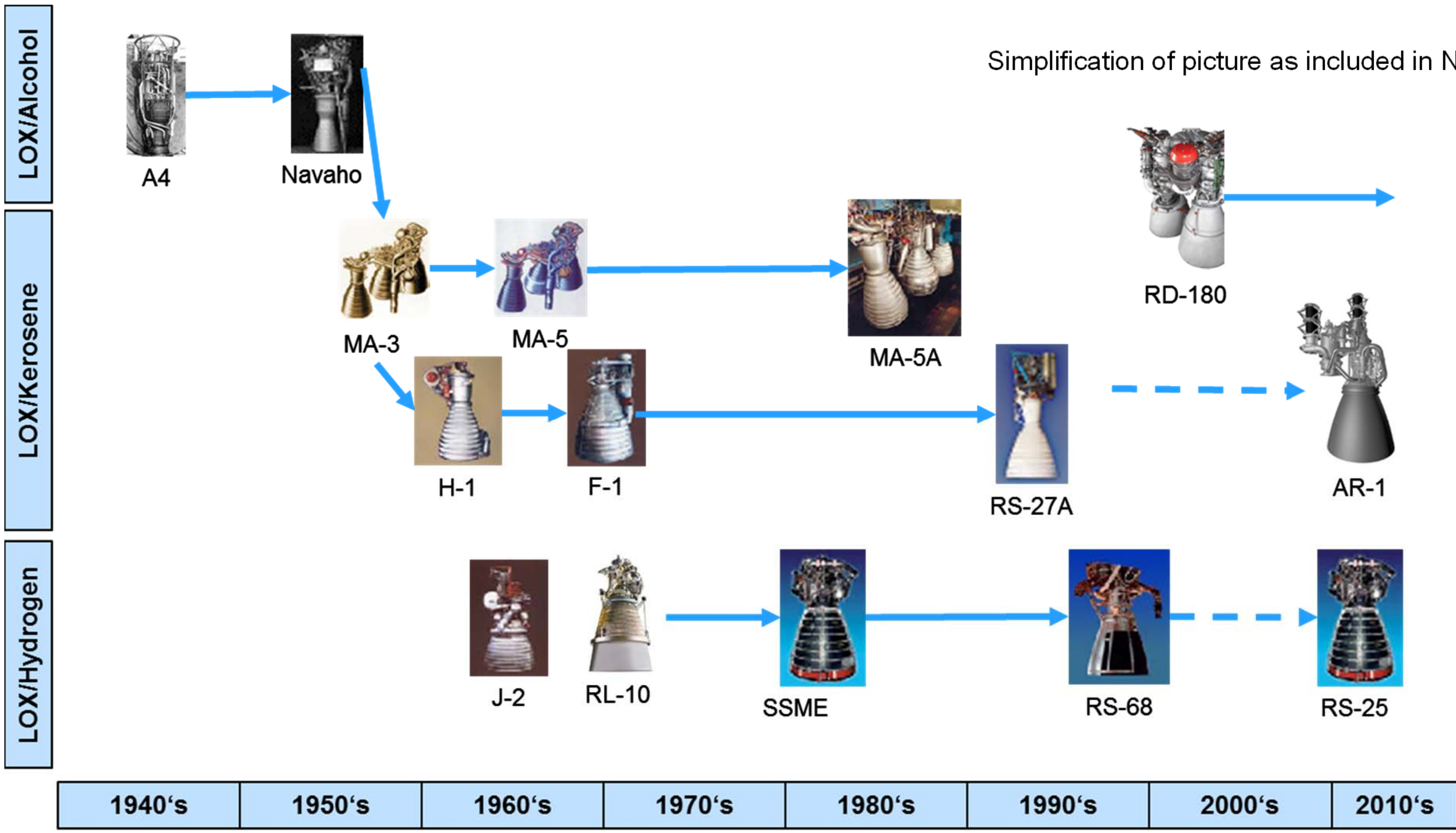
- In total, more than 1800 propellants have been investigated, with actually very few that reached flight operational status (see e.g. G. Sutton, History of Liquid Propellant Rocket Engines, AIAA 2006)

Propellant choices are typically driven by **high level requirements** and **developed competencies** inside company / home country

The Propellant Choice – a Look into History

Example: former Rocketdyne (now Aerojet Rocketdyne), with company focus on Kerosene and Hydrogen

Source:
Simplification of picture as included in NASA/CP—2005–213607



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The Propellant Choice – Example:

Driver is **Performance**

The choice is **LOX/Hydrogen**

The Propellant Choice – Example:

Driver is: **Cost**

The choice is **…**

Note: Rocket by Herge / Tintin & Milou uses nitrid acid / anilin, and a nuclear system for space flight

Is this a low cost approach ?

Pic courtesy Sixt: „In space we would not be the first, but the cheapest“

Other companies suggest e.g.

Kerosene

So … what about Methane ?

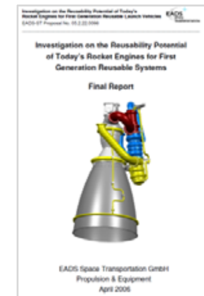
European Interest in LOX/Methane (1/2)

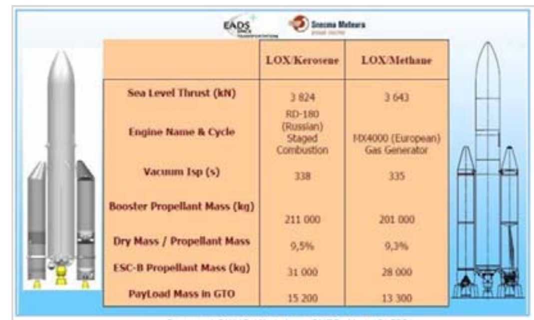
Since 2000, hydrocarbon propellant interest in studies

- 2002 – French Volga initiative for future reusable LOX/Methane Engine in cooperation with Russia

- 2004 – CNES Workshop on Hydrocarbon propellant trade (Methane vs Kerosene) activities in Europe

- 2006/9 – DLR study contract on re-usable propulsion systems





	LOX/Kerosene	LOX/Methane
Sea Level Thrust (kN)	3 824	3 643
Engine Name & Cycle	RD-180 (Russian) Staged Combustion	MX4000 (European) Gas Generator
Vacuum Isp (s)	338	335
Booster Propellant Mass (kg)	211 000	201 000
Dry Mass / Propellant Mass	9,5%	9,3%
ESC-B Propellant Mass (kg)	31 000	28 000
PayLoad Mass in GTO	15 200	13 300

Source: LOX/HC Workshop, CNES, May 12, 2004

- **Launch vehicle performance comparable** for both HC-propellants
- **Methane potential** for re-usable propulsion **superior to Kerosene**
- Strong European heritage in LOX/LH_2 further suggests **ease of mastering LOX/Methane** against LOX/Kerosene

(see e.g. DLR study final report, 2006 / 2009)

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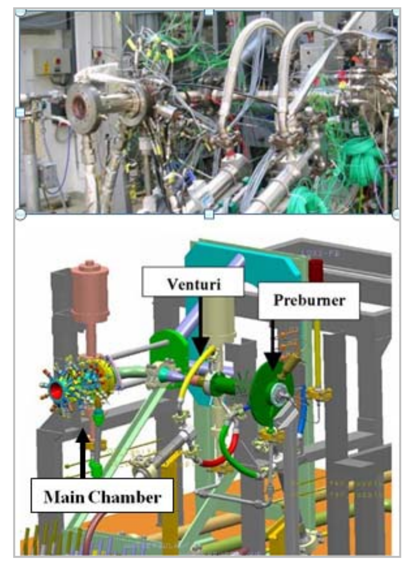
European Interest in LOX/Methane (2/2)

National and European hydrocarbon propellant technology work continued in

- DLR: TEHORA – LOX/Methane and LOX/Kerosene GG-cycle tests, and LOX/Kerosene ox-rich staged combustion test (with CADB)
- CNES: OURAL – Methanised KVD demonstrator test (with CMDB)
- ASI: LM10-MIRA demonstrator engine test, based on methanised RD-0146 (with CADB), with new chamber and fuel turbopump
- ESA: FLPP LOX/Methane fuel-rich staged combustion test



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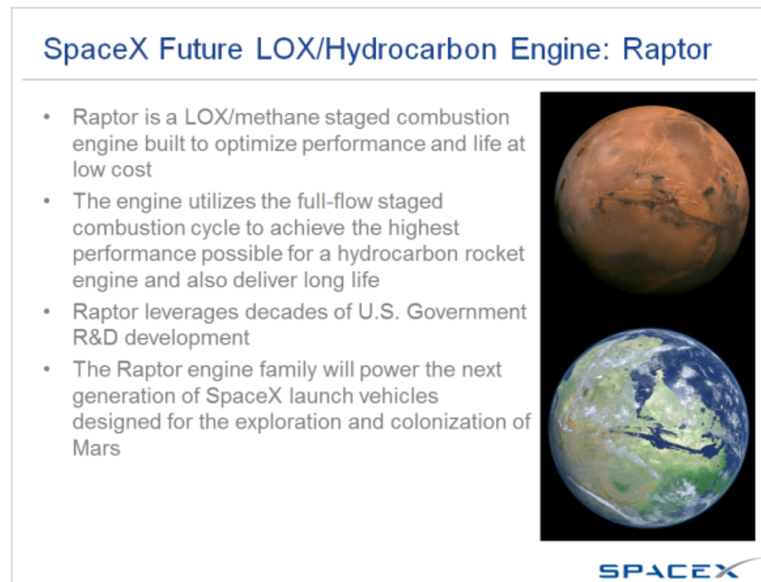
A View on Space X

- Same propellants on all stages
- Engine family (Merlin)

- LOX/Methane Raptor engine,
  full-flow staged combustion cycle
  (280 – 334 tons thrust level with two configurations)

Courtesy pictures / slides: Space X, JPC 2013

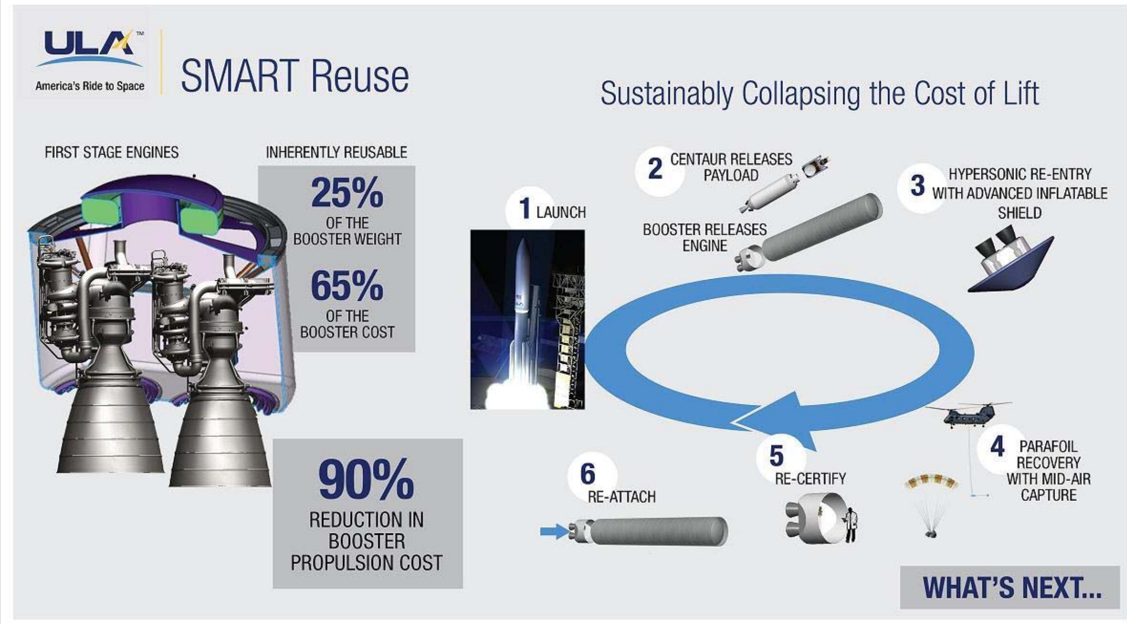


Space X pushes LOX/Methane for their next generation launcher, choice driven by :

- **Performance**
- **Low cost**
- **In-Situ (Mars)**

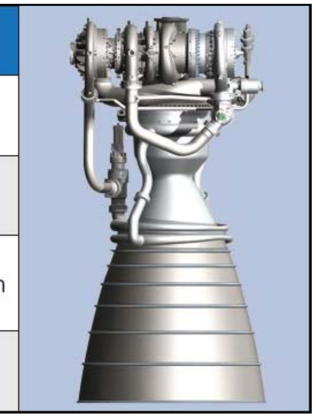
A View on ULA / Vulcan

- BE-4 LOX/Methane engine, oxidizer-rich staged combustion cycle, 240 tons thrust class
- Concept foresee re-use of the main engine bay, with an ambiguous recovery concept



Courtesy pictures: ULA

BE-4 Characteristics	
Fuel	Liquefied Natural Gas (LNG)
Oxidizer	Liquid Oxygen (LOx)
Cycle	Oxygen-Rich Staged Combustion (ORSC)
Flight	Engine ready for flight in 2017



US initiatives for **affordable & reliable access to space** build upon **LOX/Methane**

Concept feasibility of partly reusable systems to be demonstrated

How Airbus DS Prepares for Affordable & Reliable Access to Space

2 ways considered for strong cost reduction of missions:

Low-cost propulsion system
"Design-for-simplicity" and "Design-for-cost"

"Viking" type approach

- Simple technology (no regen. cooling, wall film cooling, ablative throat, etc.)
- Mid-range performance ($I_{sp}\downarrow$)
- H/W life focussing on expendability

Reusability propulsion system
"Design for maintainability, reliability, affordability, and life-cycle cost"

"ACE-R" type approach

- Tailored technology (regen. cool, life enduring mat., etc.)
- Limited maintenance effort
- H/W life focussing on re-usability (balanced life for all components)

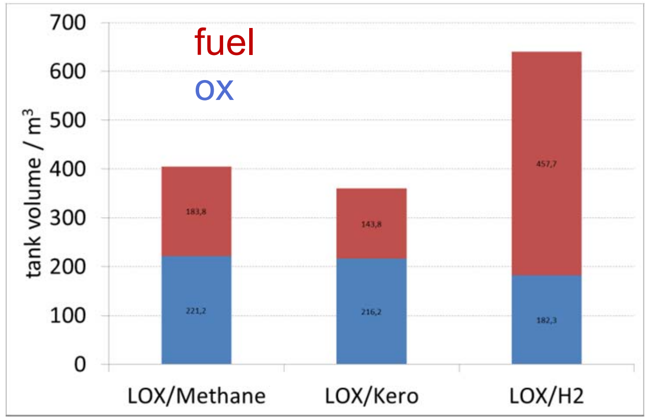
Low cost: towards 1/10 ⟺ **Reusable > x re-uses (treshold tbd.)**

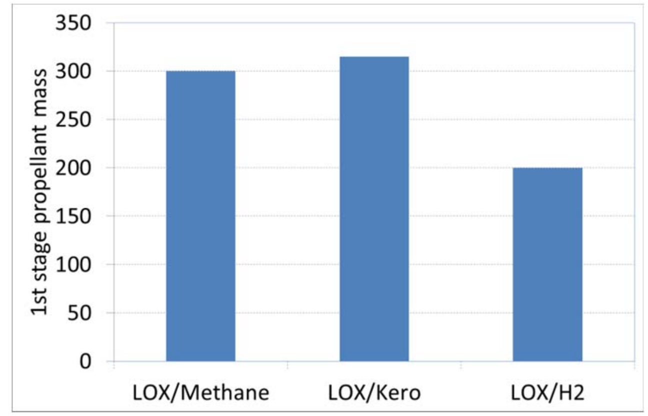
well adapted to stable launch rates ⟺ **well adapted to flexible launch demand**

The Three Propellants – System / Subsystem Aspects: Stage Design

- Compact stage, but with higher prop. mass (c.t. LH_2)
- Close to iso-volume – standard tank design

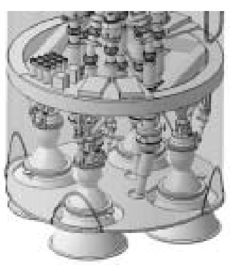
(LV study for a TSTO configuration, 3,5 tons into GTO)





Close T_s between LOX and Methane in liquid conditions opening possibilities for simpler stage design, e.g.

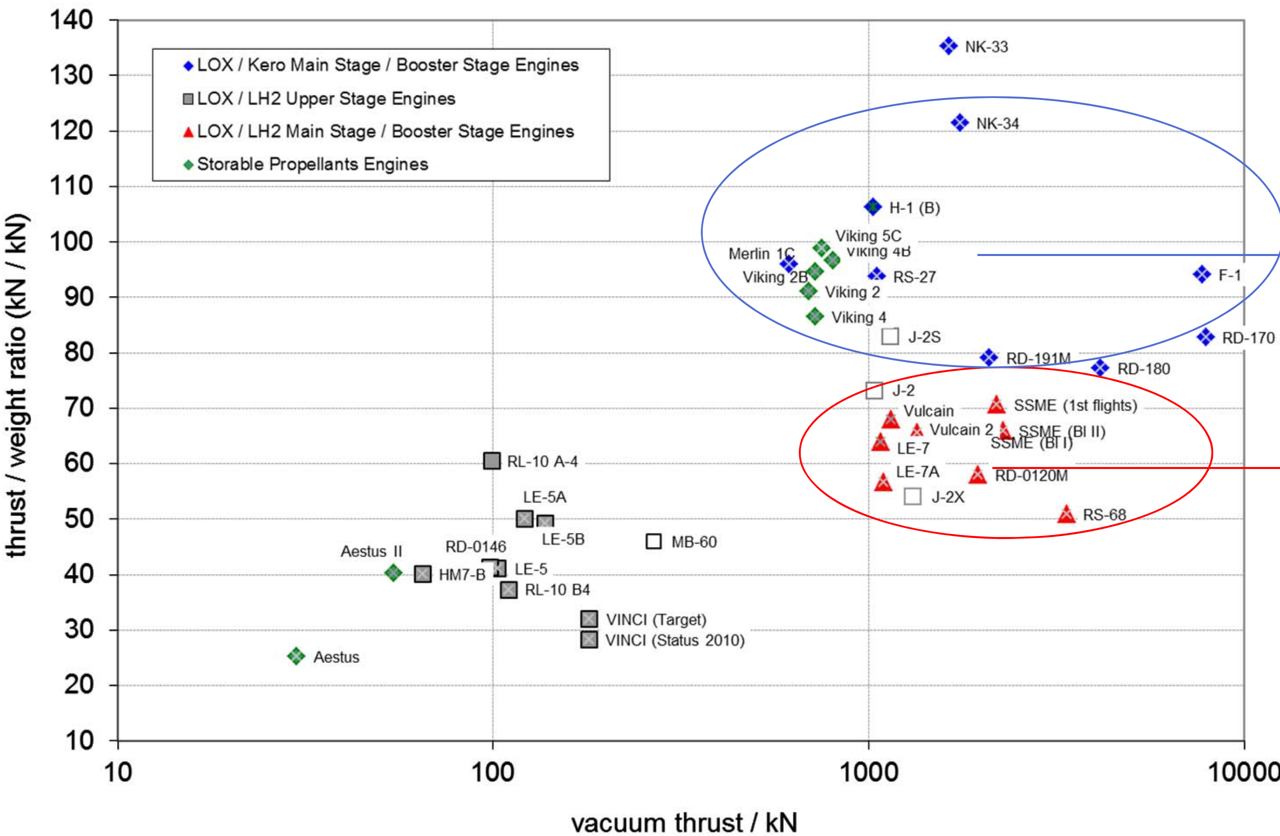
- Common bulkhead: low thermal flux allows for simpler design
- Further simplification e.g. LOX feed-line through fuel tank



Propellant combination	LOX/Hydrogen	LOX/Methane	LOX/Kerosene
Stage aspects: storage compatibility (option for compact design, common bulkhead, by $\Delta T = T_{s,Fuel} - T_{s,LOX}$)	**Challenging** ΔT = 70 K in T_s	**Feasible** ΔT = 20 K in T_s	**Extreme challenge** ΔT = 362 K in T_s

Fluid properties	Oxygen	Hydrogen	Methane	Kerosene
T_s boiling temperature (1 bar)	90 K	20 K	112 K	452 K
ρ density (liquid)	1141 kg/m³	71 kg/m³	443 kg/m³	773 kg/m³

The Three Propellants – System Aspects: Engine Thrust to Weight



LOX/HC engines with high thrust level

LOX/Hydrogen engines with high thrust level

Engine mass ratio (av.)

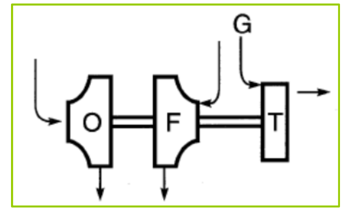
LOX/HC / LOX/LH_2 **> 1,6**

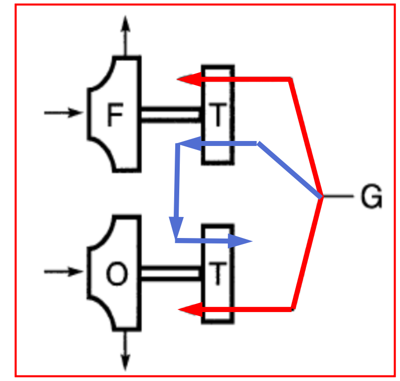
High density propellants enable compact engine design with **principle better thrust / weight ratio** compared to LOX/Hydrogen engines

Elementary conclusion with zero-order correlation engine cost vs. mass:
LOX/HC engines will be of lower cost than LOX/LH2 engines at iso-thrust level

The Three Propellants – System / Subsystem Aspects: Engine Design

- Hydrogen: Significant higher performance / power needed for fuel-side (> factor 3 above HC)
- LOX/Hydrogen: two separate pumps
- LOX/Methane and LOX/Kerosene: single shaft





- Soot-free GG or PB operation to drive turbine, with fuel-rich hot gas

Propellant combination	LOX/Hydrogen	LOX/Methane	LOX/Kerosene
Engine aspects: Simplified pump architecture (“one” pump)	**Separate TP Highest perfo**	**Single shaft TP**	**Single shaft TP**
Turbine operational condition (abrasive flow)	**No risk of soot** High energetic gas	**Low risk of soot**	**Soot** (for fuel-rich) Low energetic gas

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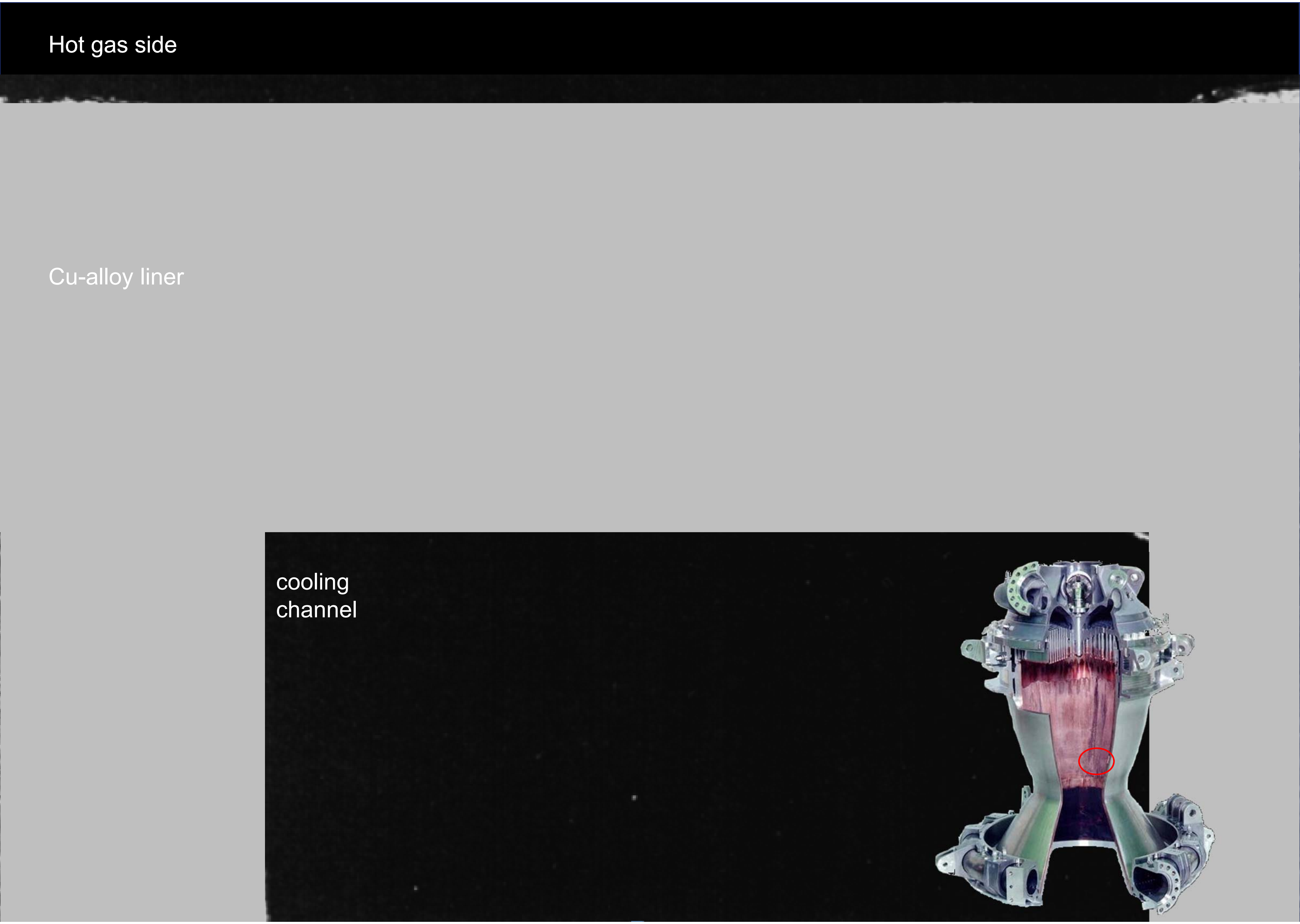
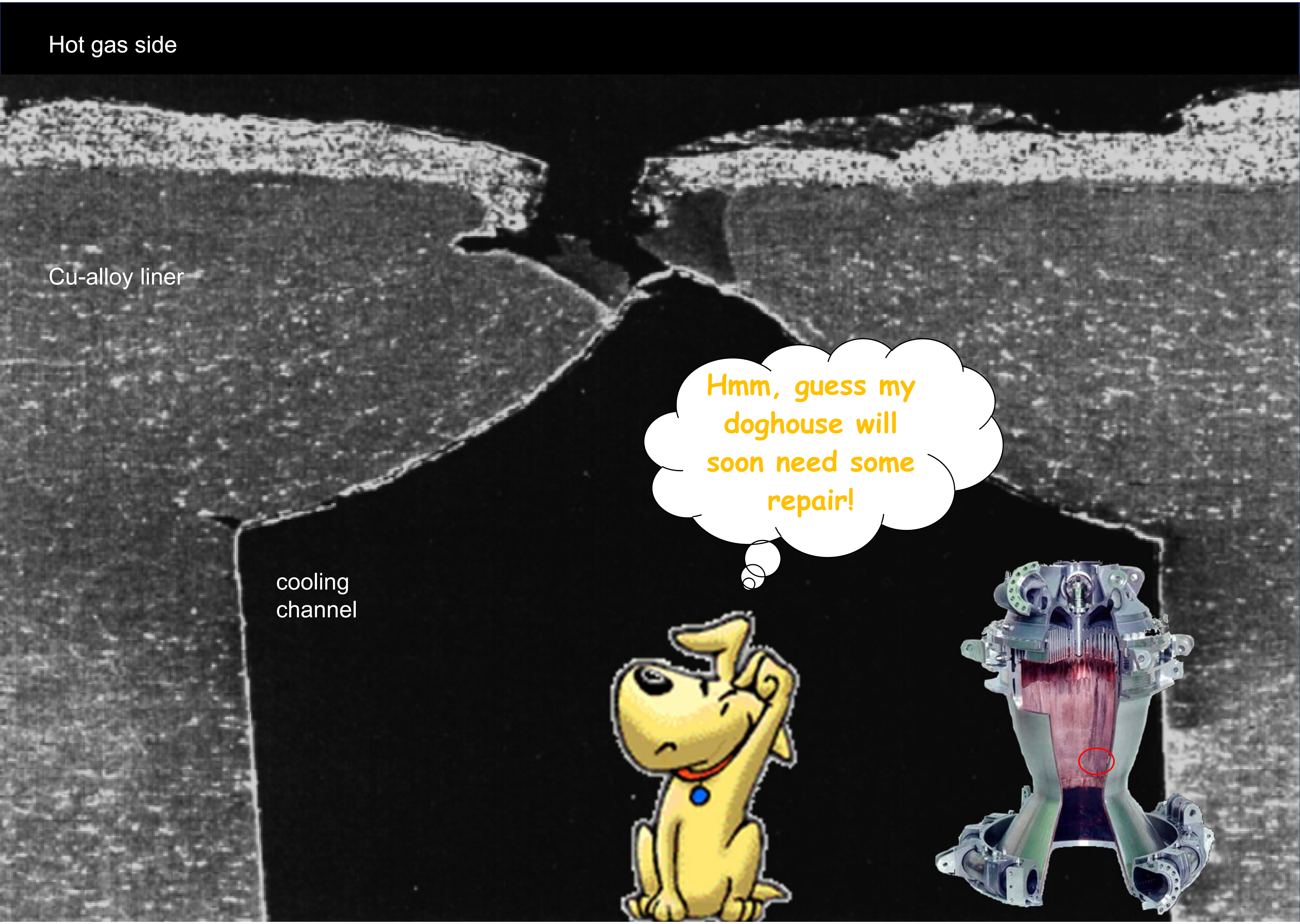
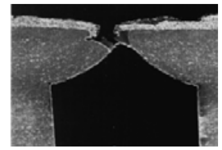

Hot gas side
Cu-alloy liner
cooling
channel

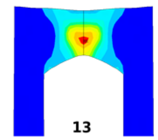

Hot gas side
Cu-alloy liner
cooling
channel
Hmm, guess my doghouse will soon need some repair!

The Three Propellants – Subsystem Aspects: TCA Reusability

Critical aspects for TCA:

- Blanching (oxidation / reduction)
- Channel cracks by cyclic plastic deformation (thermal ratcheting, "dog-house effect)
- Soot on hot gas side, coking in cooling channels (with HC)





	LOX/Hydrogen	LOX/Methane	LOX/Kerosene
Coolant performance $\Delta p/p_c$ Coking probability **)	33% -	50% low	72% medium / high *)
Blanching (oxid. /reduction)	high *)	medium / low *)	low *)
Hot gas wall temperature plastic deformations **)	~ 800 K high (2.4%)	< 650 K medium (1.4%)	< 700 K medium (1.5%)
"Safe Life Cycle" ***)	3-5	10-15	5-10

*) protection on hot gas side required, e.g. film-cooling
**) DLR study, analyses with Vulcain 2 vs ORSC LOX/RP vs FRSC LOX/CH_4, all with hot wall protection
***) "Safe Life" concept assumes liner life w/o cracks taking account of scattering/dispersions related to hardware and operational wear out

Methane – System & Operational Aspect

- Natural gas used as civil energy source with well established network (pipelines, tanks, etc.) consists of 90% - 98% of Methane
- "Synthetic" Methane can be produced **"green" → CO_2-neutral**
  - Primary energy from renewable (solar, wind, water)
  - Hydrogen via electrolysis process
  - Combination of Hydrogen H_2 with CO_2 to Methane CH_4 + O_2
  - Bio-reactor

Primary Energy	"green fuel I"	"green fuel II"
Solar Wind Other renewable	Hydrogen H_2 (via electolyse)	CO_2 Methan CH_4 (synth. Gas, SNG)
Application		
Space Transportation	Fuel for rockets Fuel cells	Fuel for rockets
"earth-bound / air-" applications (energy, transport, etc.)	Fuel Fuel cells (E-mobility)	Fuel (as LNG) (Use of existing infrastruktur – pipelines, storage vessels, etc.)

- Space exploration: In-situ propellant generation (e.g. on Mars, with H_2O and CO_2 + solar energy)

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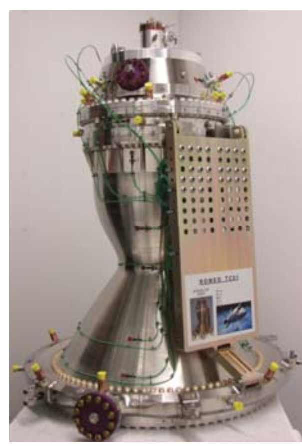
Ongoing Initiative: LOX/Methane Reusable Demonstrator Programme

- Increasing the LOX/Methane propulsion technological maturity available in Europe
- Reusability demonstration of most critical Lox/Methane rocket engine elements at large scale (basis=35 to 40 t thrust engine)

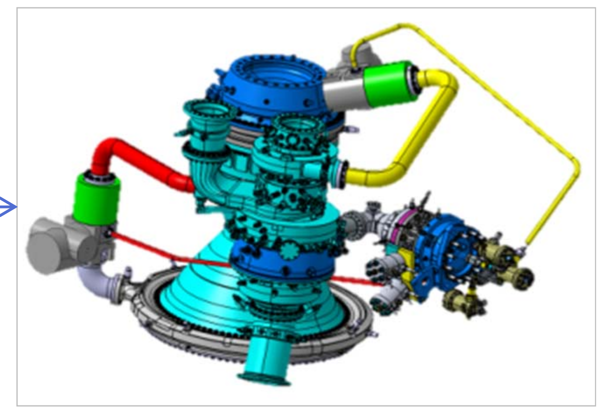
Turbopump
In cooperation with IHI (Japan)
Life target > 60 cycles

Gas Generator
Airbus DS design, life target > 60 cycles
tested in 2013

Thrust Chamber
Airbus DS design, life target > 40 cycles
tests in preparation for 2015 / 16



Engine Demonstrator
(depending on funding)



See also:
J.P. Dutheil et al., LOX/LCH4 demonstrators: IAC-14.C4.5.1

LOX/Methane thrust chamber installed
in P3.2 test facility (August 2015)

Conclusion: Airbus DS contributes to shape the future of launch vehicle propulsion beyond Ariane 6

Opportunities with LOX/Methane

- LV structure: **cost potential** against LOX/H2
- For ELV ops: **operational cost trend: lower than LOX/H2**
  (e.g. option for common gas industry infrastructure, no helium, etc.)
- For RLV: **life potential factor ~3 above Hydrogen**
  cost potential ELV vs RLV to be assessed as principle question
- Beyond LV: **Space exploration** (zero boil off, see Nasa), and **in-situ** propellant production

R&D active and open teaming:

- **Assets from Airbus DS R&T** (demonstrators) **available for further use**
  (hot firing or even flight – through institutional projects or/and industrial cooperation)

Promising technological choice

- Alignment with European & National space agencies to further develop LOX/Methane propulsion → European & national projects under preparation